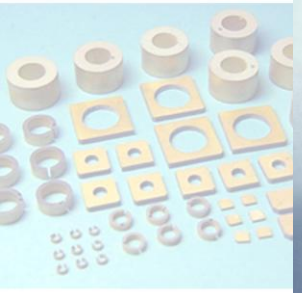
Single Crystal Piezoelectric Devices for Deformable Mirrors and other NASA Applications

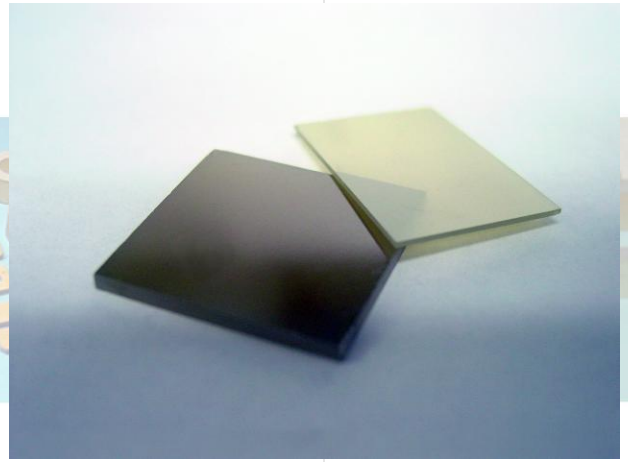
TRS Technologies Inc, State College, PA

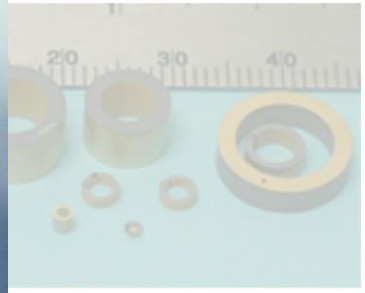
Raffi Sahul, Bun Chay Te, Michael Lapsley, and Jim Mensinger

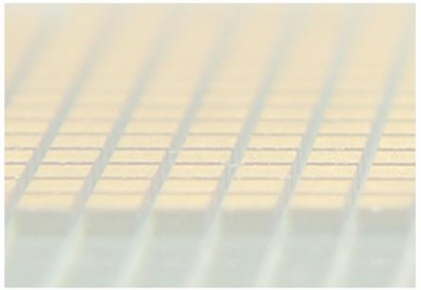
Mirror Technology Days, 2011

Jun 21, 2011









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Contractor Address: 2802 East College Avenue State College PA 16801

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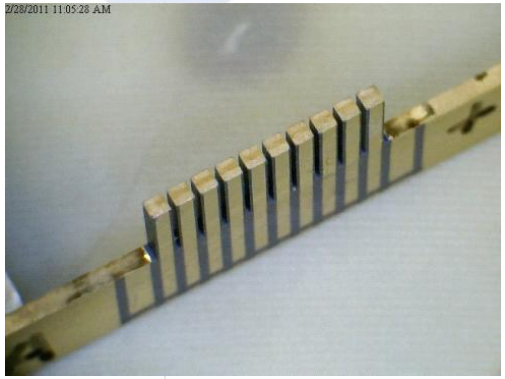
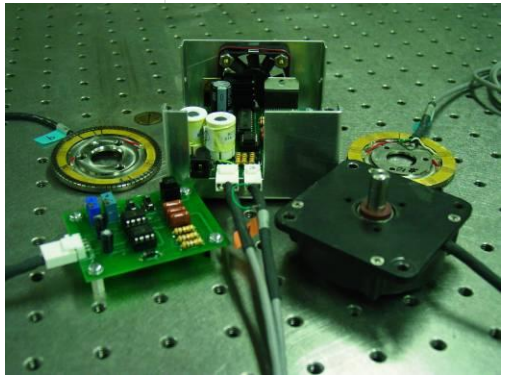
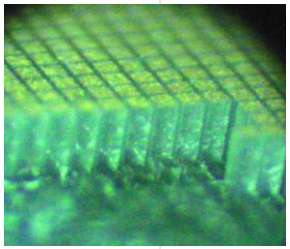
SBIR Phase II Contracts





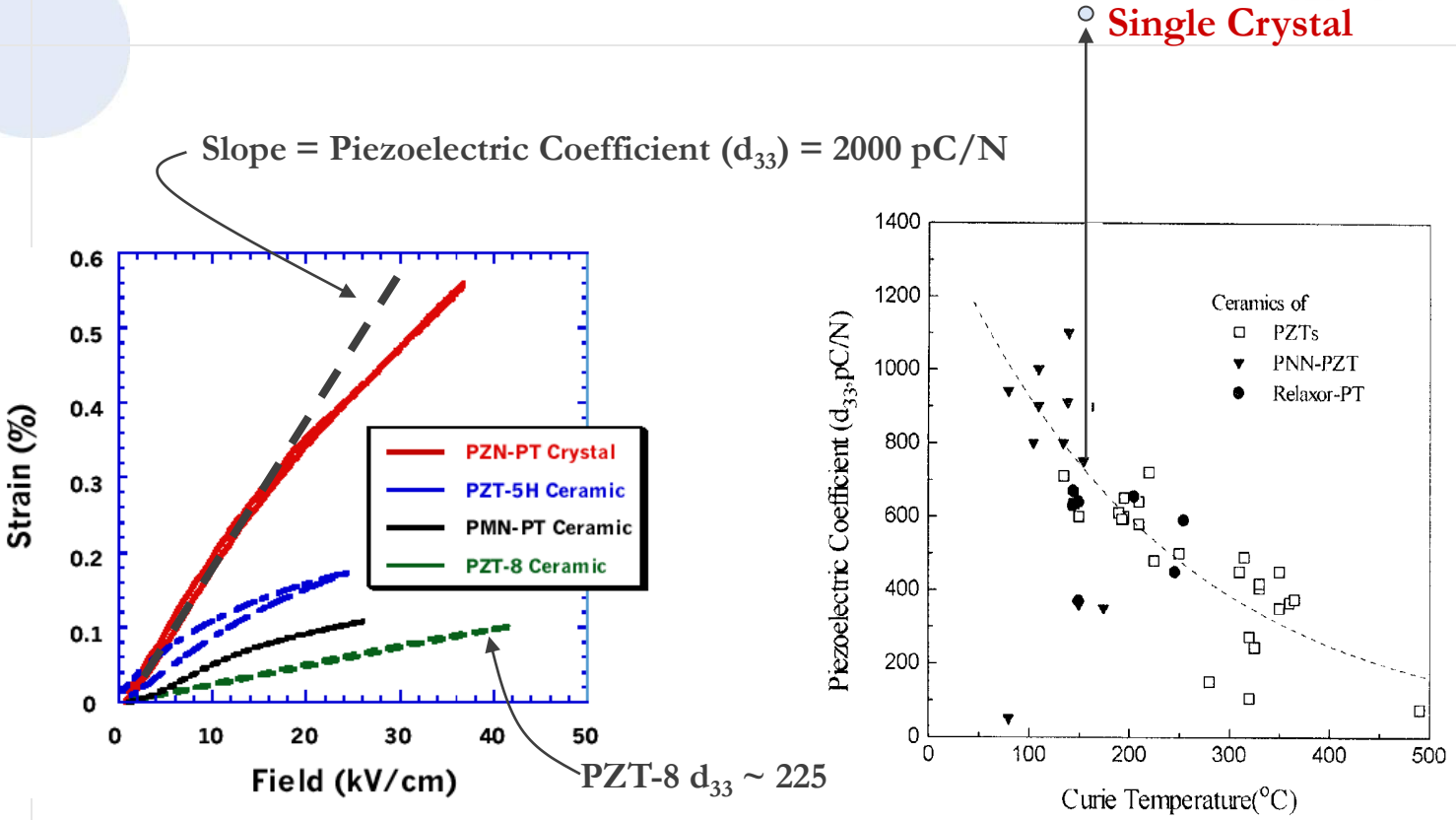
- Miniactuators for Cryogenic Deformable Mirror
  - **Contract # NNX09CA83C**
  - **Dr. Stuart B Shaklan**
  - National Aeronautics and Space Administration
  - Jet Propulsion Laboratory, Pasadena, CA 91109
  - 01/12/2009 - 01/12/2011
- Actuators for Cryogenic Fluid Valves
  - **Contract # NNX10CB12C**
  - **Brian Lusby**
  - National Aeronautics and Space Administration
  - Johnson Space Center, Houston TX 77058
  - 01/27/2010 - 01/27/2012
- Cryogenic Stepper motor
  - **Contract # NNL08AA14C**
  - **Dr. William B. Cook**
  - National Aeronautics and Space Administration
  - Langley Research Center, Hampton, VA 23681-2199
  - 11/30/2007 - 11/29/2009

Single Crystal Piezoelectrics



- ***New Transducer & Sensor Material***
  - Sonar Projectors, Hydrophones, Vibration Sensors, Flow Sensors, Ultrasonic Imaging, Actuators, Motors, etc.
- ***Largest Piezoelectric Effect Ever Observed***
  - Increased Acoustic Output Power and/or Sensitivity
  - Reduced Input Power
- ***High Electrical ↔ Mechanical Efficiency; Broad Bandwidth***
  - Improved Littoral Performance (Frequency Agile)
  - Improved Imaging/Ranging Resolution
  - Enables Multiple Functionality
- ***Dramatic System Performance, Size, and Cost Advantages***
  - Typically 2X Transducer Size Reductions
  - System Size and Power Reductions (one channel in place of two to three)
  - Many Potential System Level Cost Reductions (Size, Power, Commonality, Multi-Functionality)

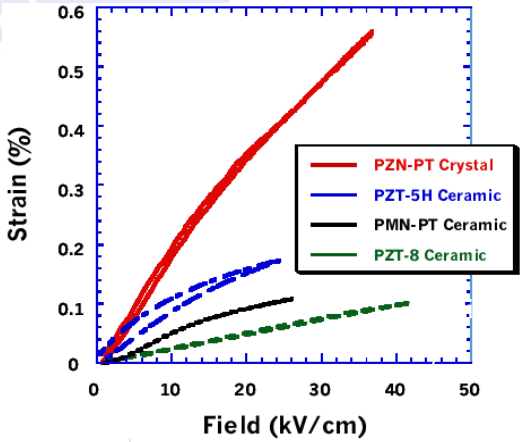
Piezoelectric Performance - <001> Polarized

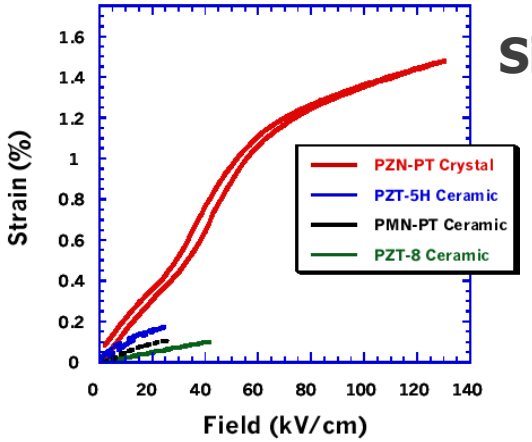


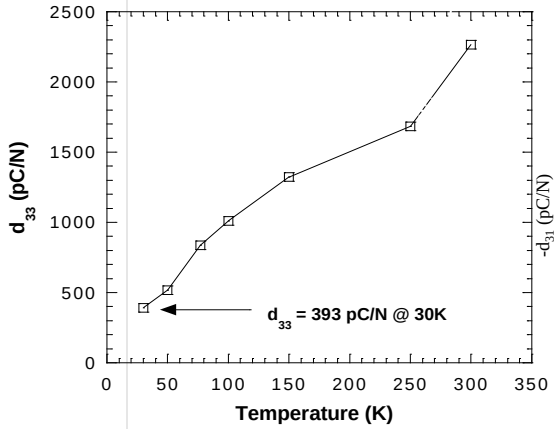
Piezoelectric Effect is 5 to 10 Times Stronger than Ceramics!!!

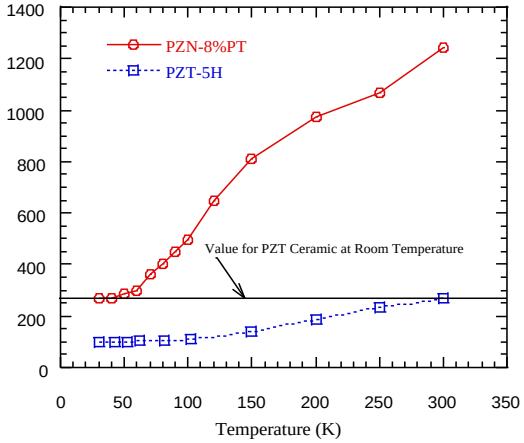
Single Crystal is "Off the Curve" Compared to Ceramic Ferroelectrics

Linear Single Crystal Piezomotor

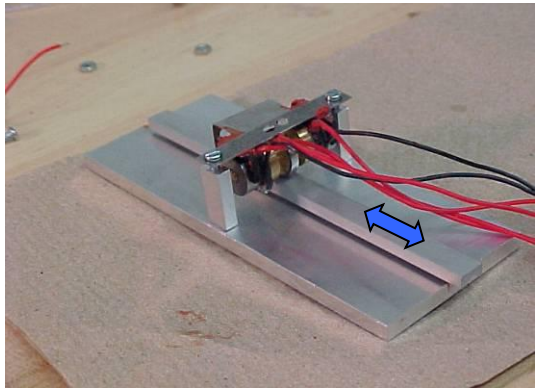








Single crystal linear motor



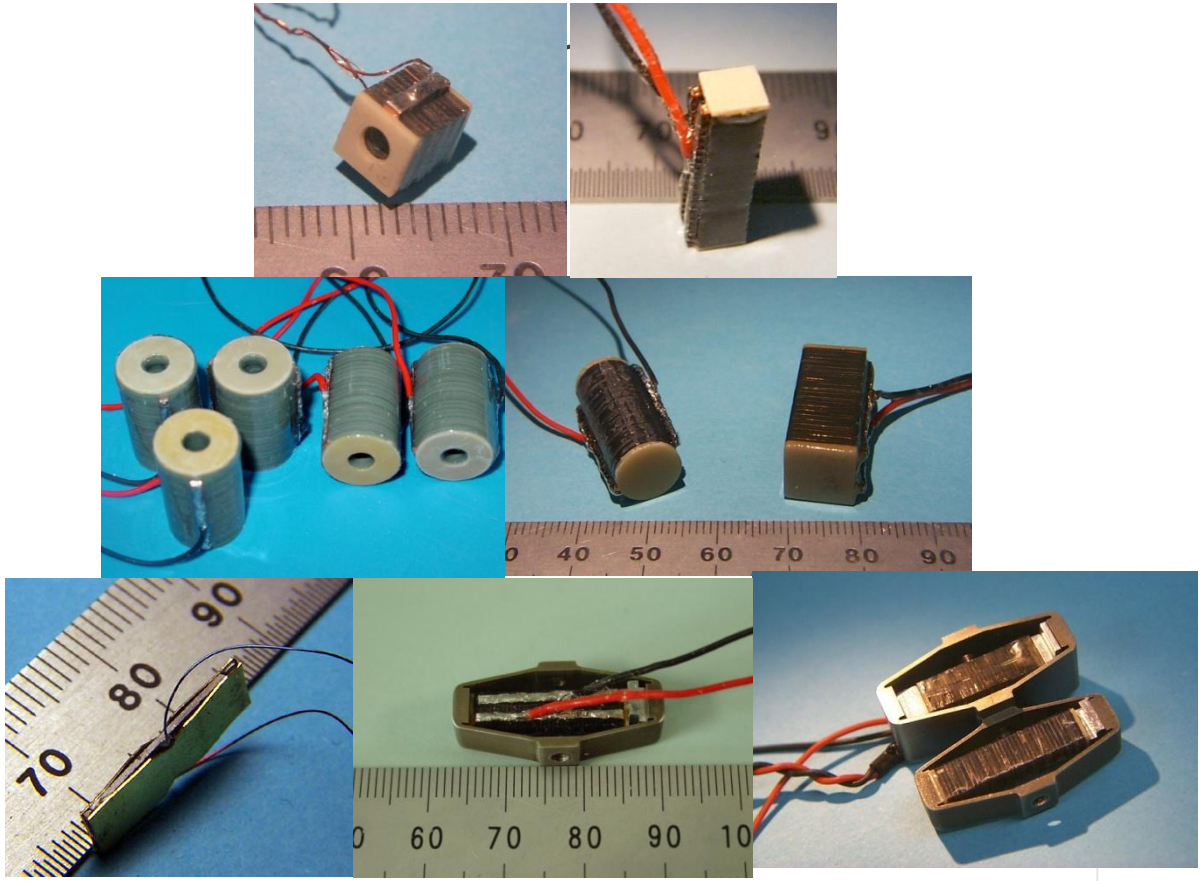
- f0 = 41.5kHz
- Driving voltage: 60-70Vpp
- Speed : 50-100mm/sec
- Force : 0.2 N
- Response time: ~ 2 ms
- Quick direction reverse
- Position hold at power off
- Operational at 77K

Single crystal piezo: large piezoelectric coefficients, excellent cryogenic properties.

Various Single Crystal Actuators

- Stack Actuator
- In-plane actuator (“31”, IDE, Shear)
- Unimorph/Bimorph
- Flextensional (moonie, cymbal, Thunder, etc.)
- HYBAS
- Polymer
- Piezomotors (ultrasonic and inertial)
- Others (compliant amplification mechanism, etc.)

TRS Single Crystal



TRS Technologies

NASA SBIR/STTR Technologies

Single Crystal Piezoelectric Deformable Mirrors with High Actuator Density and Large Stroke

Dr. Stuart Shaklan
Contract #NNX09CA83C

TRL at end of Contract: 3

Identification and Significance of Innovation

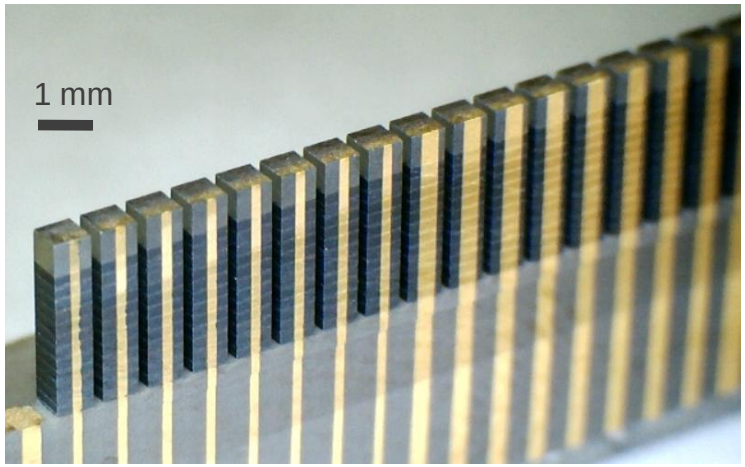
- Deformable mirrors (DM) for space based astronomical imaging systems
  - To achieve diffraction-limited performance by producing wavefront correction
  - Using feedback control loops that compensate static and dynamic aberrations in the optical system.
- Wavefront control for proximity glare suppression in astronomical cornography applications
- Single Crystal Piezoelectric materials have much higher piezoelectric properties and retain a significant percentage of these properties at cryogenic temperature. Ideal or space applications.
- Multilayer stacking produces amplification of the piezoelectric material's deflection for increased DM performance

Technical Objectives

- Broader temperature range (< 4K - > 300K) than PZT ceramics DMs
- Fine pitch (< 1mm) and high actuator density (> 1/mm2)
- Large stroke (> 2 μm, actuator height ~ 3 mm)
- Low driving voltage (< 150 V) due to high d33 ~ 2000 pC/N
- Very low strain-electric field hysteresis for high strain precision
- Low actuation heat dissipation due to very low dielectric loss (<0.01);
- High actuator density with no floating wires
- Actuator fabrication process scalable for large aperture DMs

Accomplishments

- Single crystal Piezoelectric actuator with multilayer stacking using a shimless design – no wires for connection
- 32x32 actuator array, 1 mm pitch, and 3 mm height
- Single channel high speed electronics, scalable to large array



NASA Applications

- Coronagraphic instruments
- Interferometric telescopes
- Space-based observatories
- ORIGINS program, LIDAR systems,
- Coastal Ocean Imaging systems

Other Applications

- DOD adaptive optics programs
- Directed energy
- Biometrics (retina imaging)
- Active vibration control and structure morphing
- RF communication tuning,
- Cryogenic microscopy tools,
- Micro/nanofabrication and nanoassembly

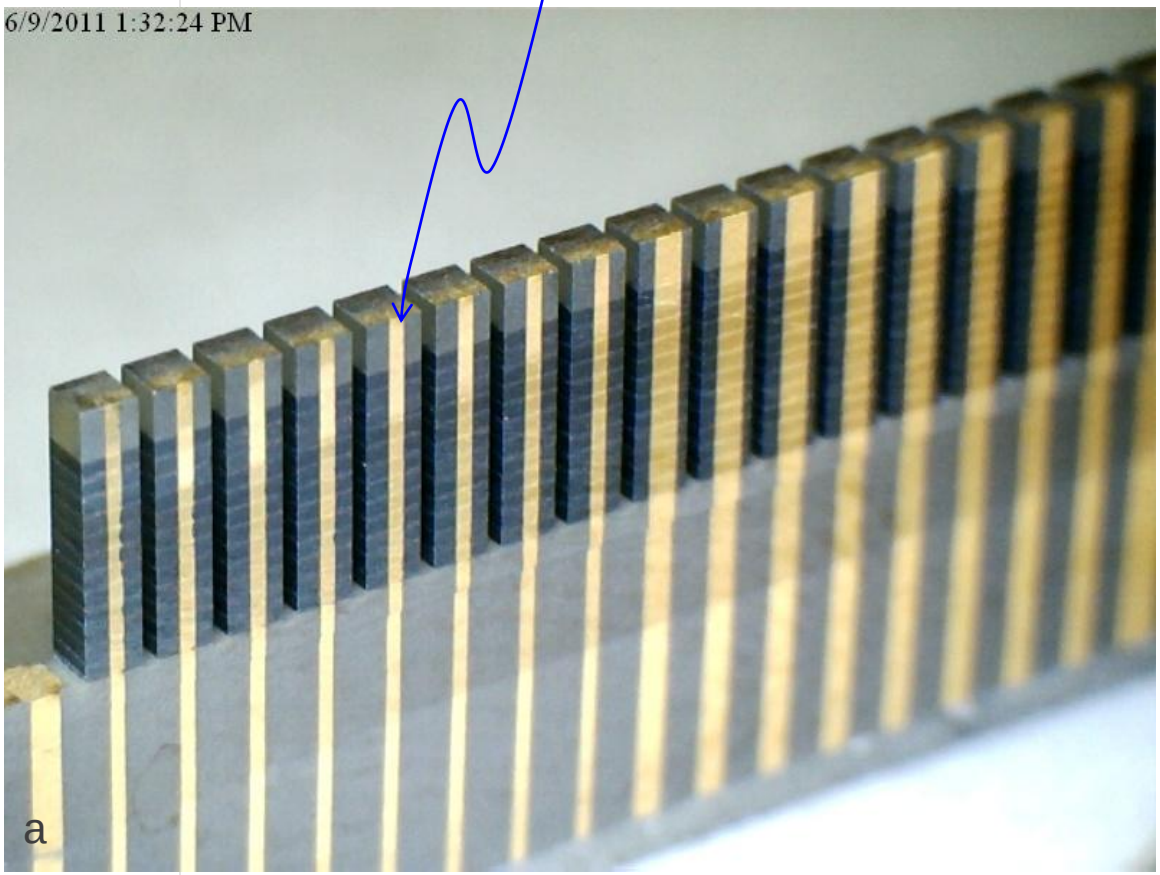
Contacts

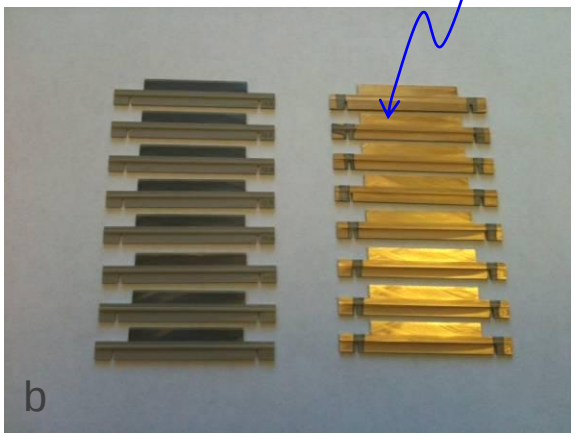
Bun Chay Te, PI, 814-238-7485
Stuart B Shaklan, PhD. NASA JPL

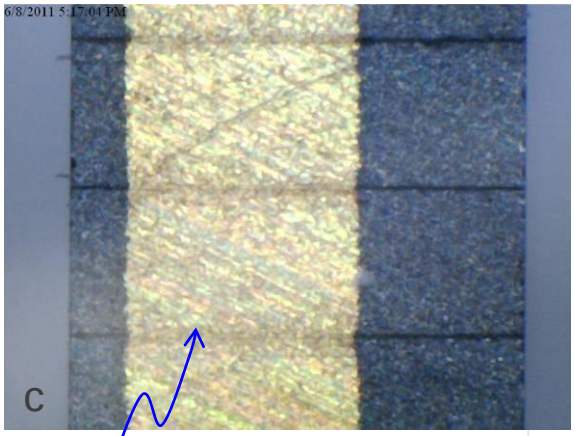
Single Crystal Piezoelectric 1x32 Actuator Arrays with Varies Sidewall Electrodes

Laser etched electrode, then diced into actuators (0.8x0.8x3mm)

Sputtered with gold

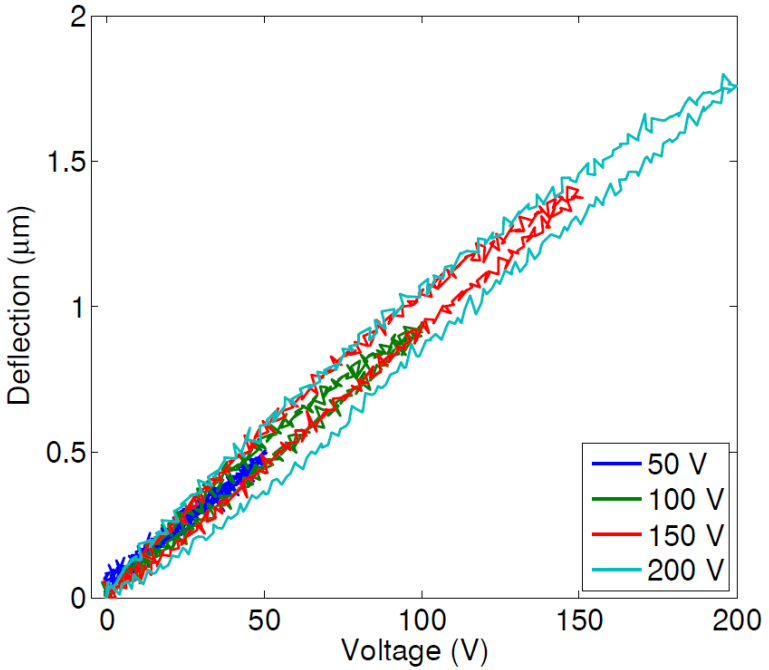


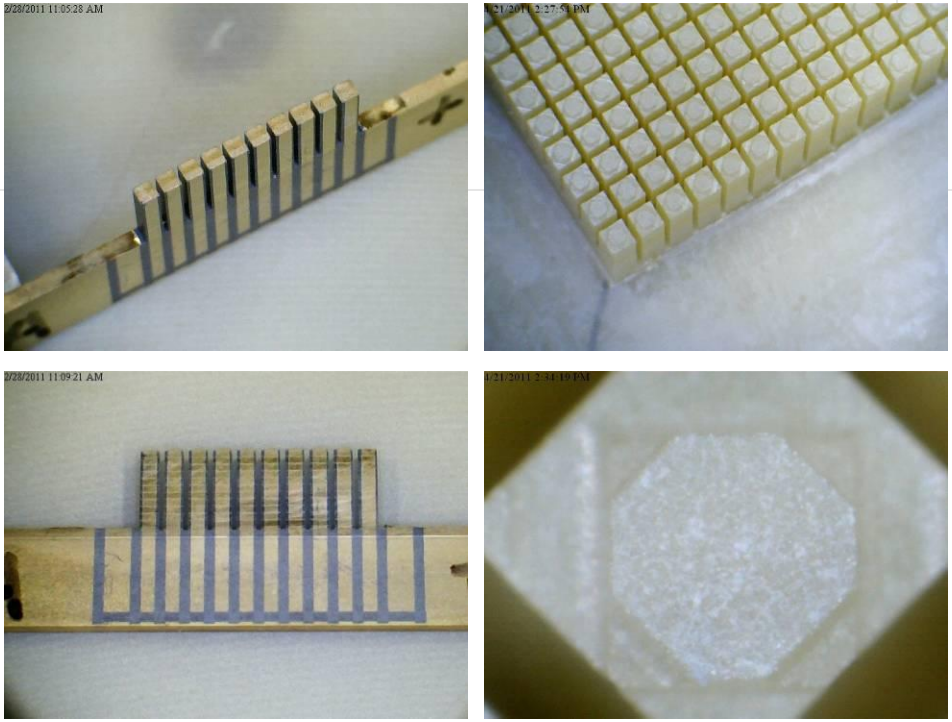




Sidewall electrode connections

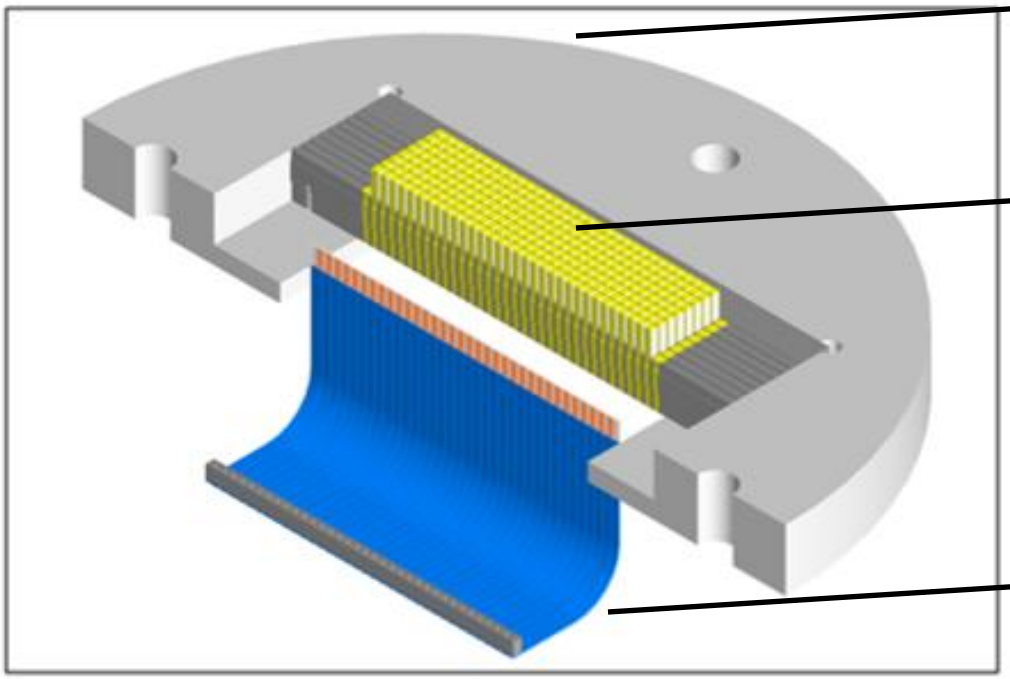
Single Crystal Piezoelectric 1x10 Actuator Array and 32x32 Octagonal Pedestals





- Each actuator element is 0.8 x 0.8 x 3.3 mm
- 1 x 10 array actuator array produced ~1.75 micron deflection at 200 V
- Actuator elements diced with octogonal pedestals to reduce stress while bonding to facesheet

Single Crystal Actuators for Deformable Mirror



- Illustration of the final deliverable
- 32 x 32 channel fine DM single crystal array with flex circuitry connections and mounted to mirror facesheet
- Cryogenic performance test down to 77 K
- DM performance testing to be performed by JPL

NASA SBIR/STTR Technologies

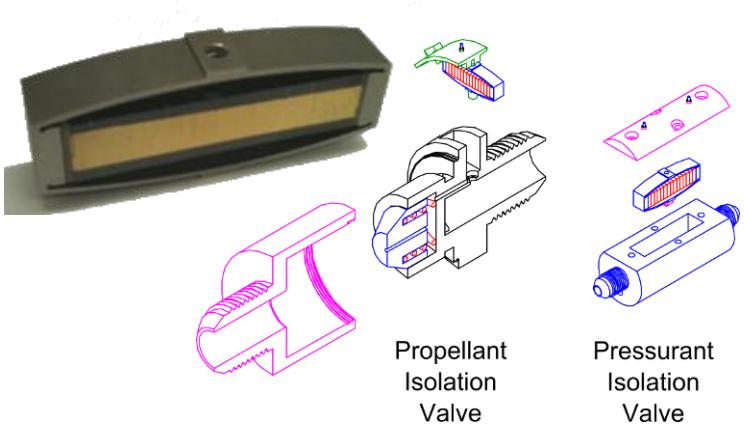
Cryogenic Fluid Transfer Components Using Single Crystal Piezoelectric Actuators

TPOC: Brian Lusby
Contract # NNX09CE60P

TRL at end of Contract: 4

Identification and Significance of Innovation

- Cryogenic fluid transfer and handling for spacecraft propulsion, launch facility ground processing, and lunar surface systems are critical to the advancement of NASA's exploration goals. Low profile and highly efficient cryogenic electromechanical actuators are needed for these applications.
- Cryogenic fluid transfer components using PMN-PT single crystal piezoelectric actuators
- Demonstrated in Phase I showed benefits of a low profile, fast response, light weight, low power consumption, low thermal dissipation, high reliability, and broad operation temperature range.



Technical Objectives

- Develop a flextensional actuator with stroke > 1.5 mm and force > 80 N
- Integrate flextensional actuator into two separate cryogenic valves: one for high pressure (4500 psia) and another for high flow rate (13 lbm/s).
- Develop driving electronics for the flextensional actuators
- Investigate the actuator and valve reliability and design optimization
- Deliver 2 isolation valves of each type to NASA for further evaluations

Accomplishments

- Development of high stroke actuators for valve control.
- Actuation of a low and high pressure puppet valves using multiple frame-actuator assemblies for flow control of gas at pressures up to 3000 psi at cryogenic temperatures (phase 1).
- Multi-turn needle valve integrated with a piezomotor for low pressure (200 and 300 psi) flow control at cryogenic temperatures (phase 1).
- New valve and actuator designs for high pressure and high flow rate valves using only a single frame actuator.

NASA Applications

- Exploration (space craft propulsion, launch facility ground processing, lunar surface systems.
- Earth Based (Propellant conditioning and cryogenic densification)

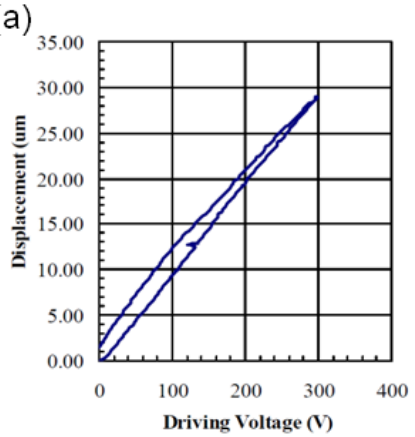
Non-NASA Applications

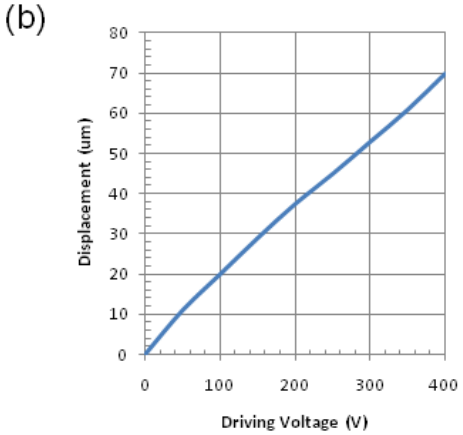
- Large stroke, high precision actuators for:
- Adaptive optics, active vibration control, structure morphing, RF communication tuning, bio-medical manipulators, photonics, cryogenic microscopy tools, micro/nanofabrication and nanoassembly

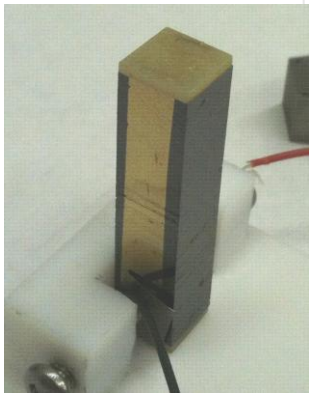
Contacts

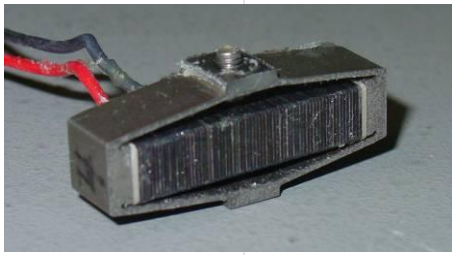
Bun Chay Te, PI, 814-238-7485
Brian S Lusby , NASA Johnson Space Center

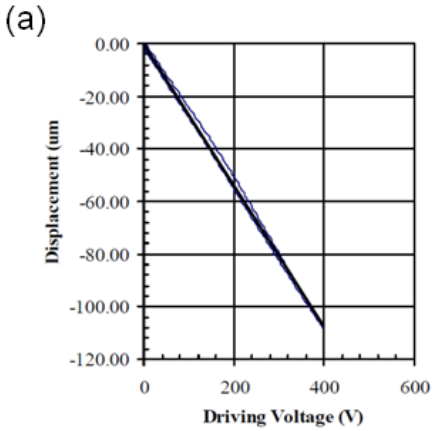
Single Crystal Actuators

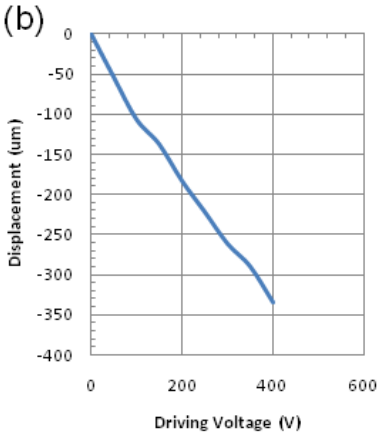




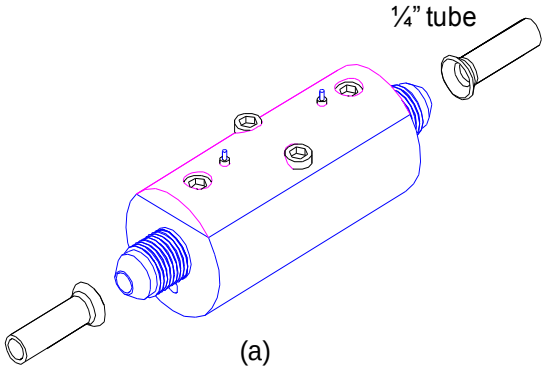


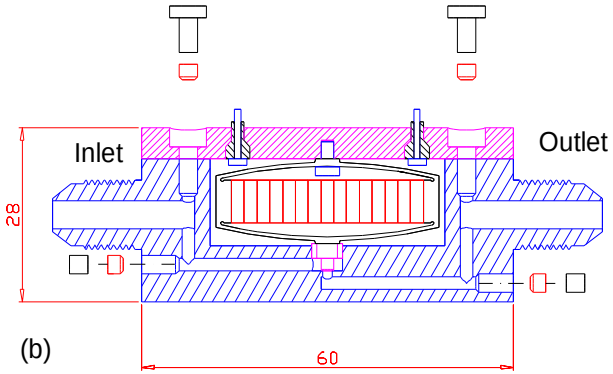






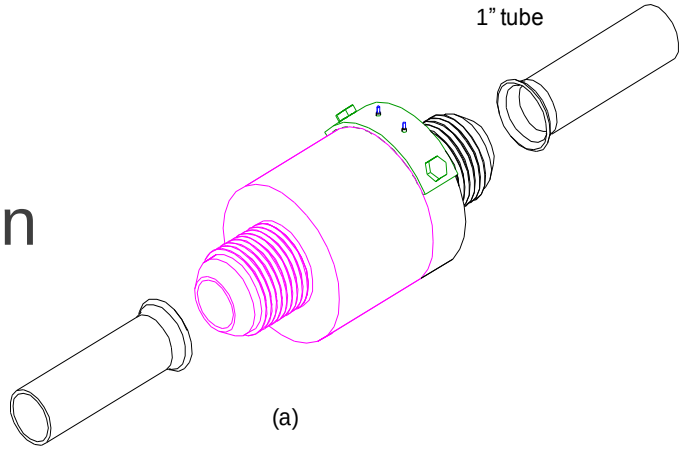
Cryogenic Valves

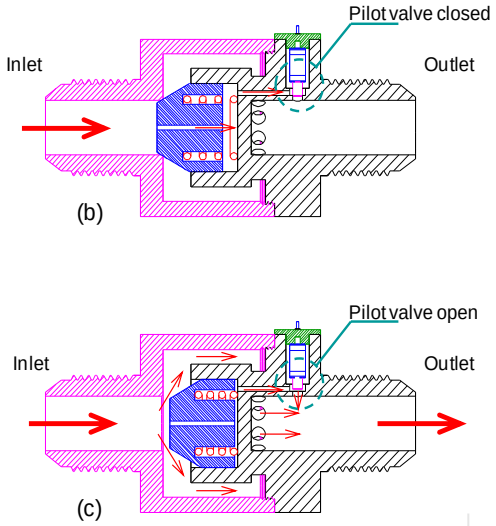




High Pressure - Pressurant Isolation Valve

High Flow rate - Propellant Isolation Valve





TRS Technologies

NASA SBIR/STTR Technologies

Cryogenic Stepping Piezomotor for Large Torque, Precise Rotary and Linear Motion Control in Passive Optics

Dr. Bill Cook
Contract #NNL08AA14C

TRL at end of Contract: 4

Identification and Significance of Innovation

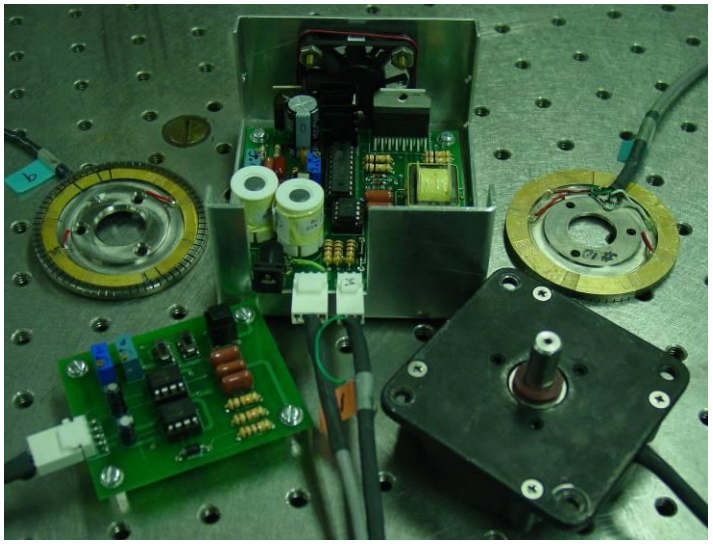
- Stepping motors with large torque, precise rotary and linear motion control, small profile, and low power consumption are desired for passive optics in space and airborne IR remote sensing platforms.
- Compared to electromagnetic, piezoelectric traveling-wave motors have low power consumption, small size, and zero power holding torque.
- Single crystal piezoelectrics exhibit 3 to 5 times the strain of conventional piezoelectric ceramics, have very low strain hysteresis, and retain excellent piezoelectric performance at cryogenic temperatures.

Technical Objectives

- Develop stepping motors with large torque and high resolution
- Demonstrate the precision alignment and positioning control using the developed cryogenic stepping motors with fine pitch screws
- Develop cryogenic driving electronics for cryogenic stepping motors
- Deliver 4 cryogenic stepping motors to NASA for further evaluations.

Accomplishments

- Produced Room temperature driving electronics and cryogenic switches
- In depth analysis on impedance matching
- Cryogenic testing chamber for real-time characterization of the motors
- Cryogenic bearings were designed and fabricated using Rulon
- Fabricated 12 cryogenic stators implementing bimorph design and PMN-PT single crystal plates
- Produced 5 functional cryogenic motors for delivery



NASA Applications

- Etalon scanning and tip-tilt mirror control
- Deformable mirror positioning
- Precision positioning for large space telescopes
- Manipulator arms and precision stages

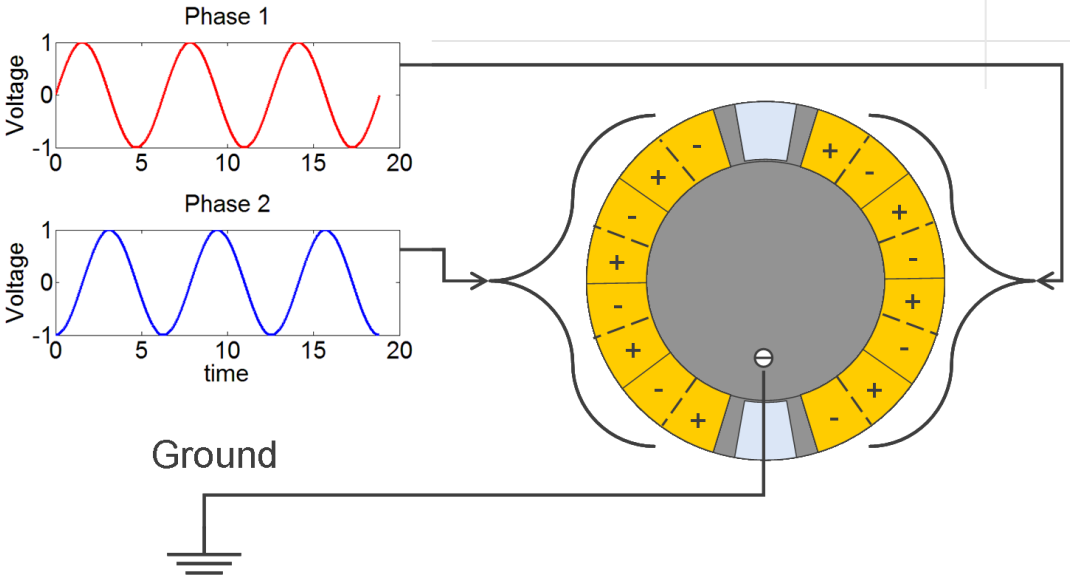
Non-NASA Applications

- Tuning for DOD microwave devices
- Robotics and precision positioning stages
- Precision medical valves and pumps.
- Vehicle accessories (electric windows, headlight positioners, mirror positioners, etc.).

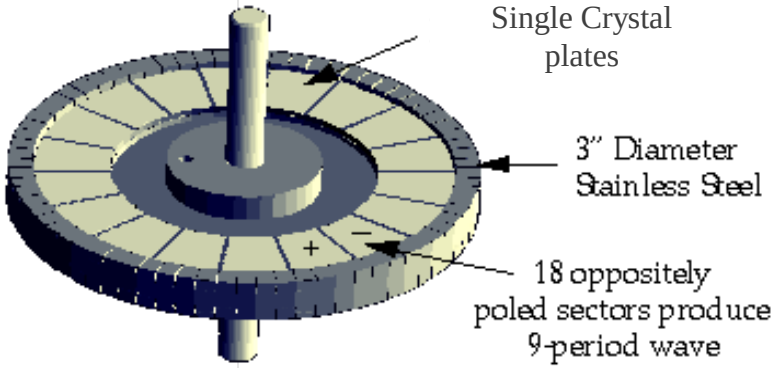
Contacts

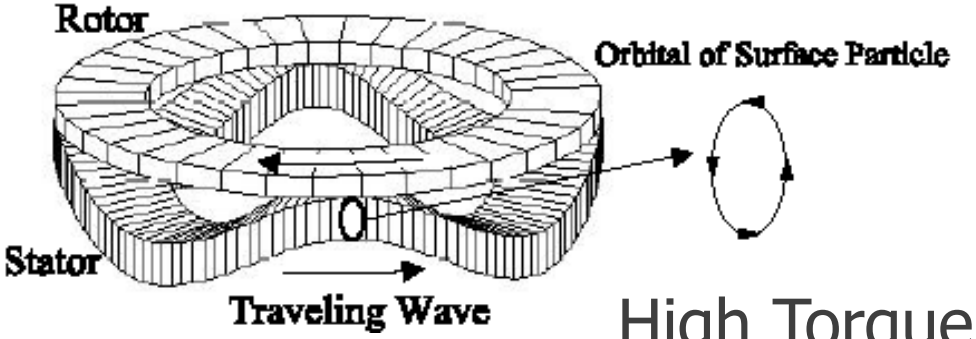
Wesley Hackenberger, Ph.D., PI, 814-238-7485
William B. Cook, Ph.D., COTR, NASA Langley, 751-864-8331

Flexural Traveling Wave Ultrasonic Piezomotor



Prototype Design

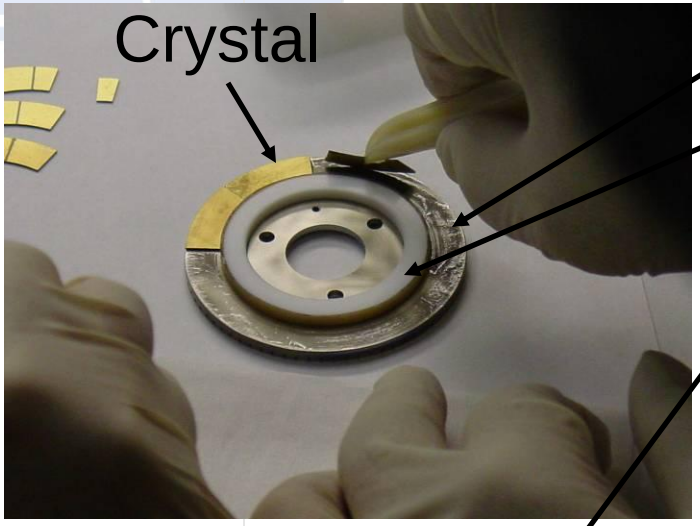




High Torque

Resonant condition, high efficiency, both rotary and linear motor.

Motor Assembly



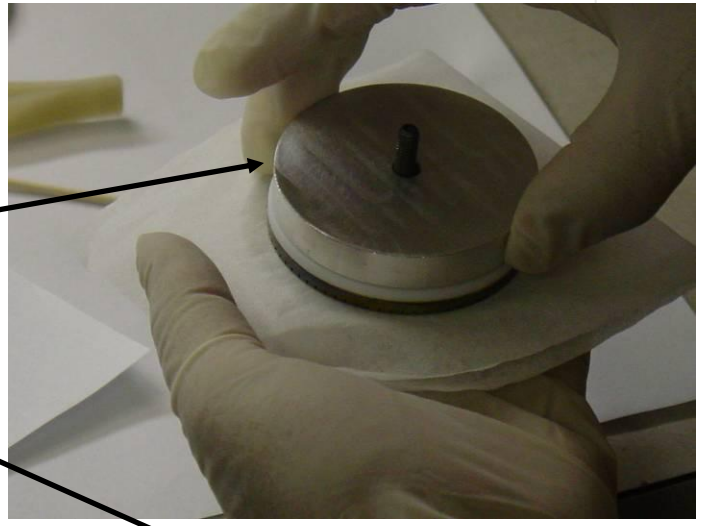
Stator

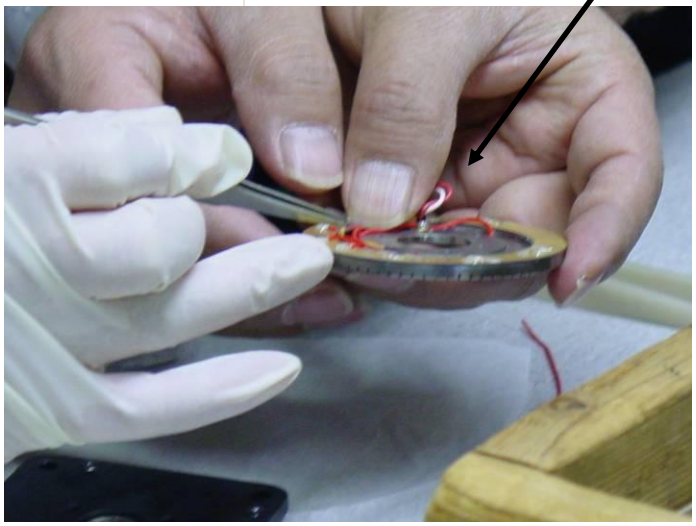
Spacer

Weight

Wires

Spring/Clutch





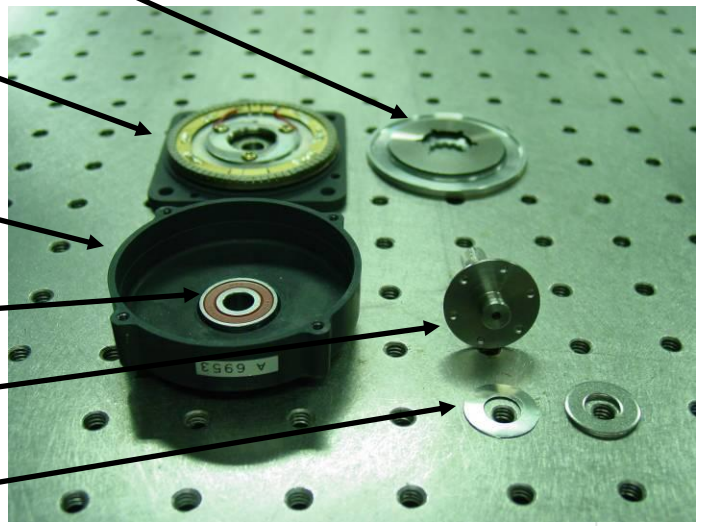
Stator/Top

Bottom

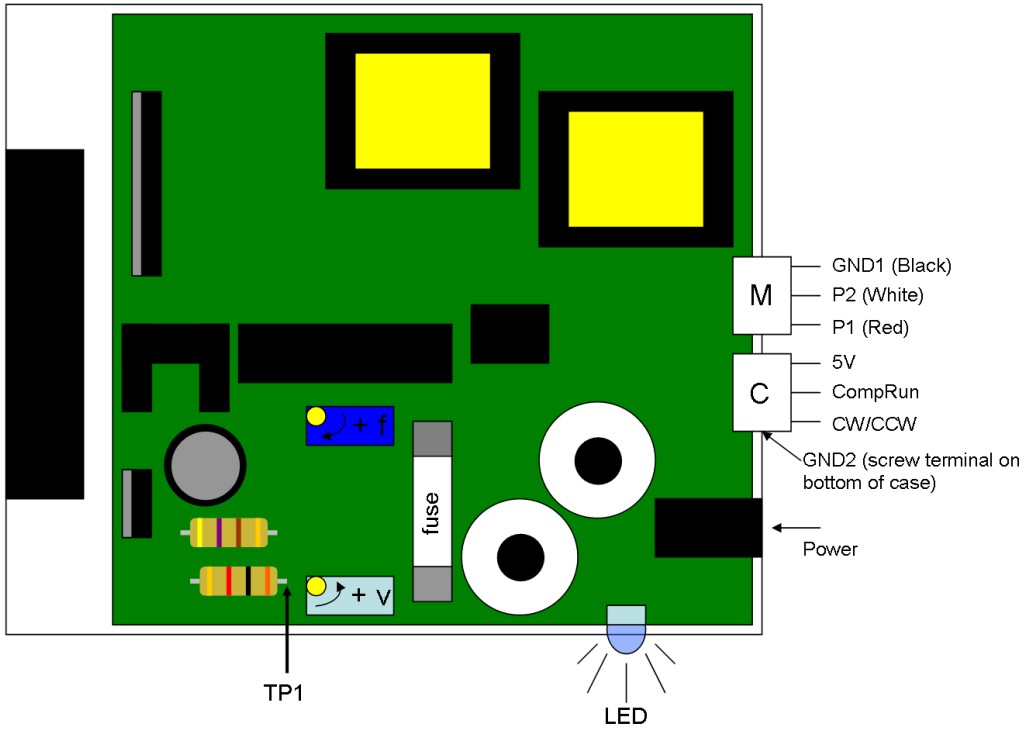
Bearing

Shaft

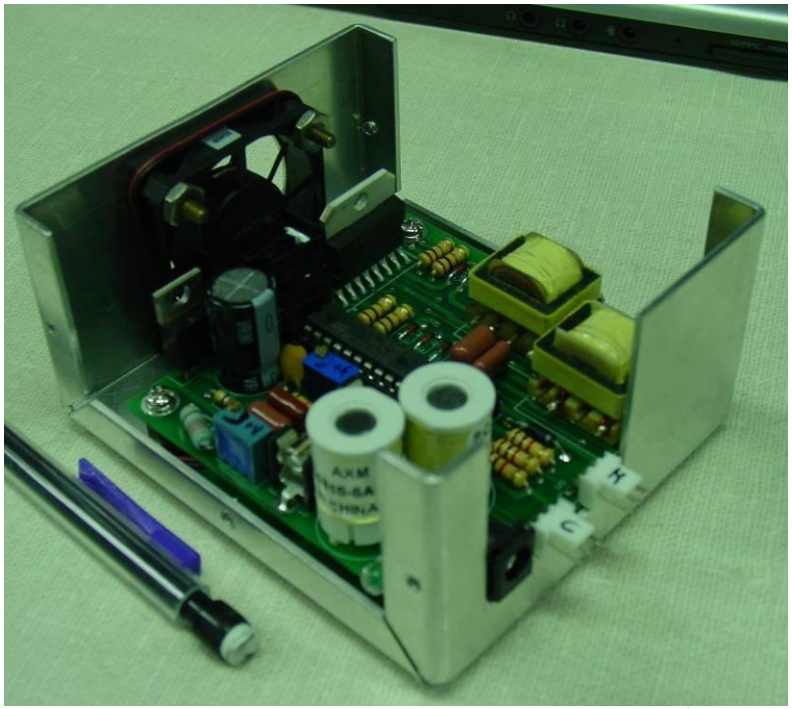
Shims



Driver electronics for Stepper Motor



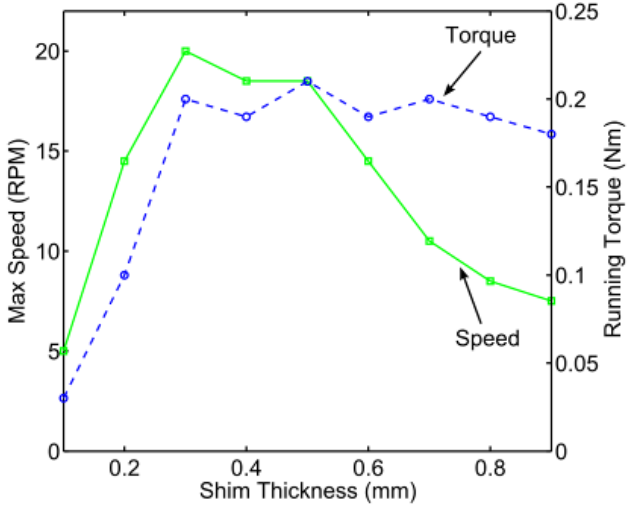
Dimensions
3.5” X 4” X 2”



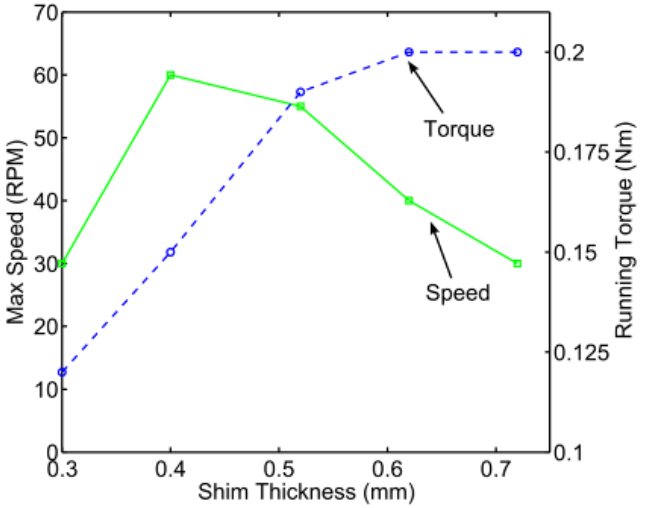
- Tunable Voltage and Frequency
- Current over 3 Amps Peak
- Simple TTL Logic Input Controls
- 15VDC Power

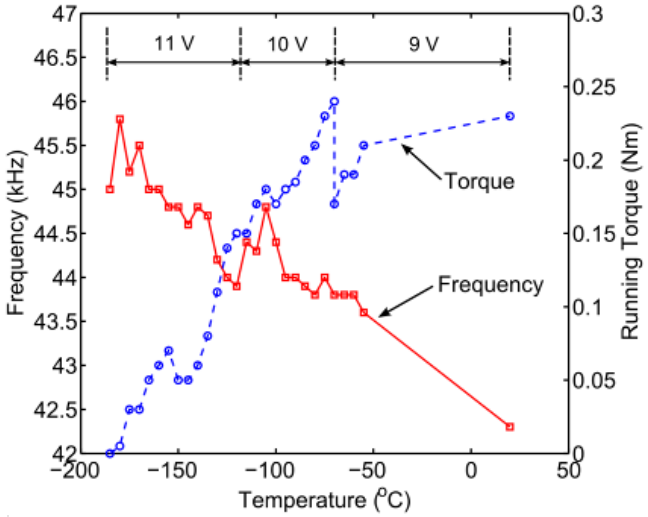
Motor Performance

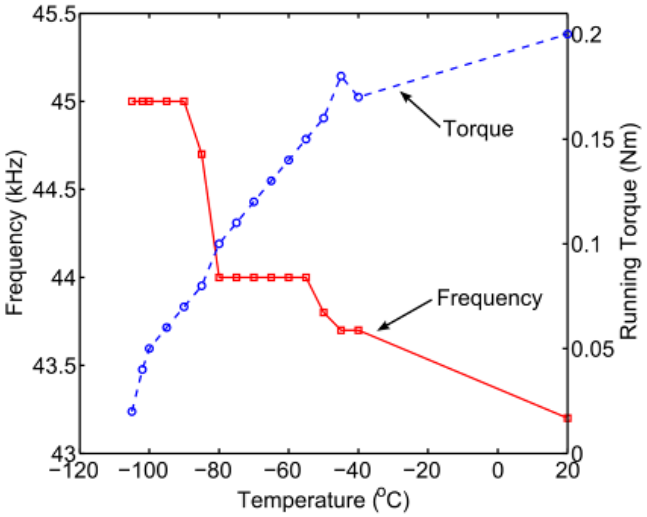
TRS8



TRS10



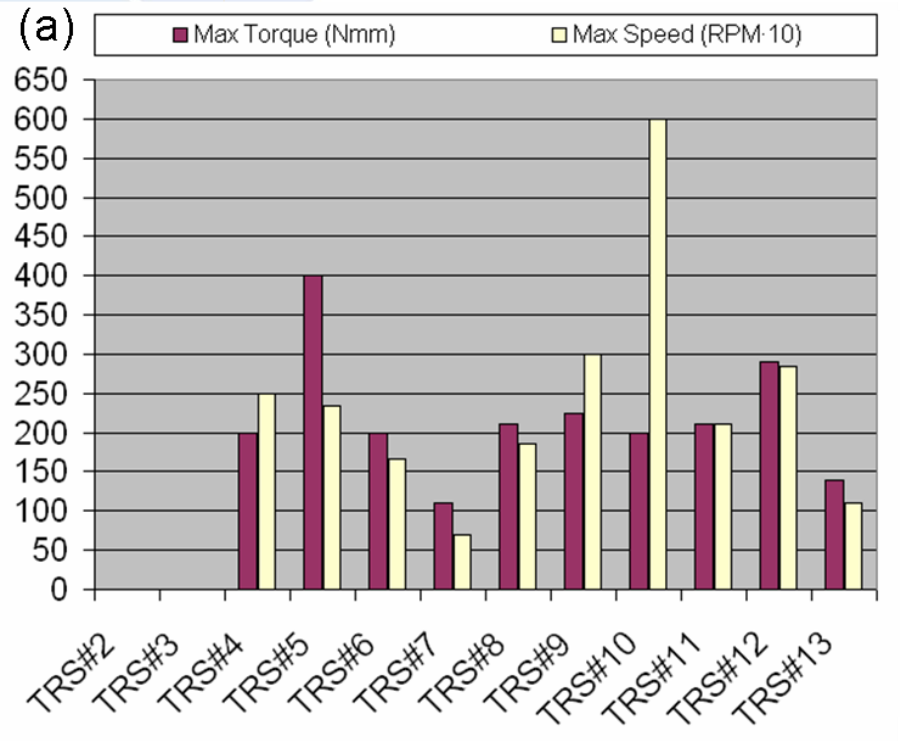


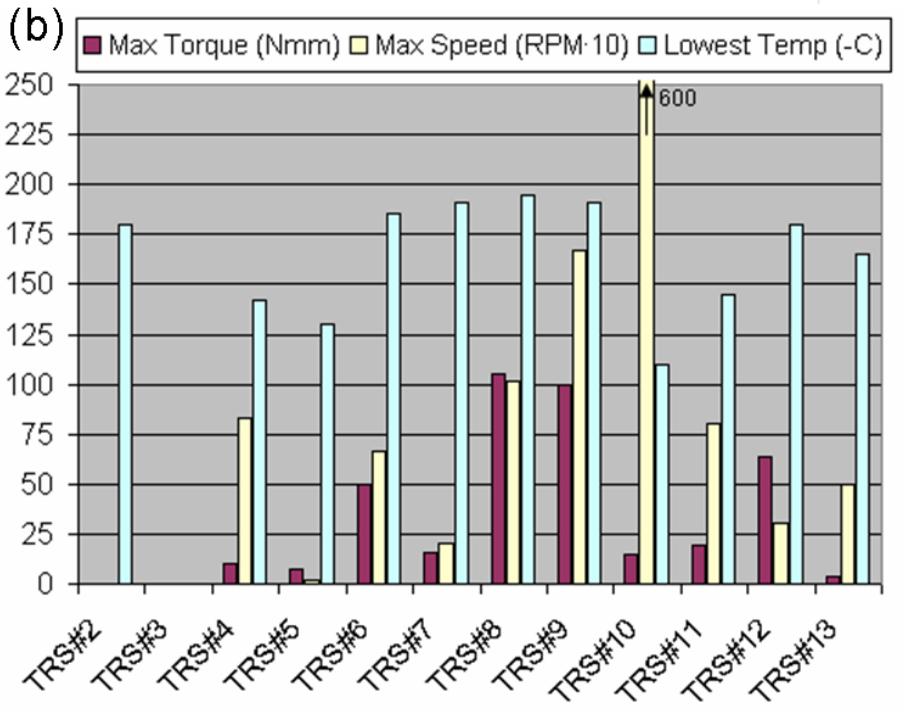


RT
0.15Nm
80RPM
0.15W

Cryo
0.1Nm
100RPM
0.2W

Motor Performance Summary





Step Angle Resolution

500 µs pulse

Average step 0.055°to 0.158° ± 0.01°

TRS Technologies

Conclusion/Summary

- Miniaturized single crystal based actuators for deformable mirrors – scalable technology
- Single crystal actuators for cryogenic fluid transfer
- Single crystal cryogenic motors for passive optics control
- Umbrella technology applicable for broad variety of NASA and other defense/commercial applications
- Currently growing 3” diameter crystals that are 100 mm tall in production – this has significantly reduced cost of single crystals to \$0.5-\$0.6/mm^3